

Remediation of soil and groundwater
Rizlan Bernier-Latmani
Problem set # 4: vapor phase processes
Solution

Problem 1:

Select units: mg for toluene; g for cells; m³ for volume; min for time.

$$Q = 0.3 \text{ m}^3 \cdot \text{h}^{-1} = 0.3 \frac{\text{m}^3}{\text{h}} * \frac{1 \text{ h}}{60 \text{ min}} = 5 * 10^{-3} \text{ m}^3 \cdot \text{min}^{-1}$$

$$C_i = 560 \text{ } \mu\text{g} \cdot \text{L}^{-1} \text{ air} = \frac{\mu\text{g}}{\text{L}} * \frac{1000 \text{ L}}{1 \text{ m}^3} * \frac{\text{mg}}{10^3 \mu\text{g}} = 560 \text{ mg} \cdot \text{m}^{-3}$$

$$h = 1 \text{ m}$$

$$V = ?$$

$$k = 120.3 \text{ mg toluene} \cdot (\text{g cell} \cdot \text{min})^{-1}$$

$$K_s = 17.4 \text{ mg} \cdot \text{L}^{-1} \text{ air} = 1.74 \frac{\text{mg}}{\text{L}} * \frac{1000 \text{ L}}{1 \text{ m}^3} = 1.74 * 10^3 \text{ mg} \cdot \text{m}^{-3}$$

Initial biomass $X = 1 \text{ g cells} \cdot \text{L}^{-1} = 1000 \text{ g cells} \cdot \text{m}^{-3}$ (expressed as a function of volume of air flow not volume of bed)

This is intended to be the biomass concentration that is present at the operational state of the biofilter.

Monod model for growth:

$$\frac{dC}{dt} = - \frac{kX}{C + K_s} C$$

We assume that X is constant (equal growth and death of microorganisms) and we see that $C_i \ll K_s$
Hence, the equation simplifies to:

$$\frac{dC}{dt} = - \frac{kX}{K_s} C$$

Which corresponds to first order kinetics:

$$C_{out} = C_{in} e^{-\frac{kX}{K_s} t} = C_{in} e^{-k' t}$$

We can calculate k' :

$$k' = \frac{kX}{K_s} = \frac{120.3 \frac{\text{mg toluene}}{\text{g cell min}} * 1000 \frac{\text{g cell}}{\text{m}^3}}{17.4 * 10^3 \frac{\text{mg toluene}}{\text{m}^3}} = 6.91 \text{ minutes}^{-1}$$

We are missing t , the residence time of air in the reactor (called EBCT):

$$EBCT = \frac{V}{Q} = \frac{\pi r^2 h}{Q}$$

We don't have the radius of the biofilter, let's do a sensitivity analysis to determine how the effluent concentration depends on the biofilter diameter:

$$C_{out} = C_{in} e^{-k' EBCT} = C_{in} e^{-k' \frac{\pi r^2 h}{Q}}$$

We calculate:

r (m)	0.03	0.04	0.05	0.06	0.1	0.15
EBCT (min)	0.6	1.0	1.6	2.3	6.3	14.1
Cout (mg/m3)	11.25	0.54	0.01	0.00	0.00	0.00

Clearly, the larger the radius the more removal. However, the residence time in the biofilter becomes too high when the radius exceeds 10 cm and the removal may not be sufficient if the

diameter is below 4 cm.

So, we can pick 10 cm diameter (5 cm radius). The effluent concentration is then 0.01 mg.m^{-3} .

Problem 2:

Air stripper to remove ethylbenzene.

We choose consistent units: volume = m^3 ; mass=g, distance=m and time=s.

What is the height of the air stripping column?

$Z = \text{NTU} \cdot \text{HTU} \rightarrow$ Need to calculate HTU and NTU

$$C_{\text{EB,aq,in}} = 1 \frac{\text{mg}}{\text{L}} * \frac{1000\text{L}}{1\text{m}^3} * \frac{1\text{g}}{1000\text{mg}} = 1 \frac{\text{g}}{\text{m}^3}$$

$$C_{\text{EB,aq,out}} = 35 \frac{\mu\text{g}}{\text{L}} * \frac{1000\text{L}}{1\text{m}^3} * \frac{1\text{g}}{10^6 \mu\text{g}} = 0.035 \frac{\text{g}}{\text{m}^3}$$

$$Q_w = 643.45 \frac{\text{L}}{\text{min}} * \frac{\text{m}^3}{1000\text{L}} * \frac{1\text{min}}{60\text{s}} = 1.07 * 10^{-2} \frac{\text{m}^3}{\text{s}}$$

column diameter = 0.915 m $\Rightarrow$ surface area of tower is $S = \Pi * (d/2)^2 = 0.66 \text{ m}^2$

air: water ratio=100:1 $\rightarrow Q_A/Q_w=100$

$$K'_H = 0.27 [-]$$

$$T = 20^\circ\text{C}$$

To calculate HTU, we need to calculate L, the liquid mass loading rate

$$L = \frac{Q_w \rho_L}{S} = \frac{1.07 * 10^{-2} \frac{\text{m}^3}{\text{s}} * 998200 \frac{\text{g}}{\text{m}^3}}{0.66 \text{ m}^2} = 1.63 * 10^4 \frac{\text{g}}{\text{m}^2 \cdot \text{s}}$$

The liquid molar loading rate L_M can be calculated by $L_M = L / \text{MW}_{\text{water}}$

$$L_M = \frac{1.63 * 10^4 \frac{\text{g}}{\text{m}^2 \cdot \text{s}}}{18 \frac{\text{g}}{\text{mol}}} = 9.04 * 10^2 \frac{\text{mol}}{\text{m}^2 \cdot \text{s}}$$

We also need to calculate $K_L a$:

$$K_L a = \alpha D_L \left(\frac{L}{\mu_L} \right)^{1-n} \left(\frac{\mu_L}{\rho_L D_L} \right)^{0.5} = \alpha D_L \left(\frac{Q_w \rho_L}{\mu_L S} \right)^{1-n} \left(\frac{\mu_L}{\rho_L D_L} \right)^{0.5}$$

With $\alpha=330$ and $n = 0.22$ given by the packing.

$$\begin{aligned} \text{Thus: } K_L a &= 330 \cdot 6 \cdot 10^{-10} \left[\frac{\text{m}^2}{\text{s}} \right] \cdot \left(\frac{1.07 \cdot 10^{-2} \left[\frac{\text{m}^3}{\text{s}} \right] \cdot 998200 \left[\frac{\text{g}}{\text{m}^3} \right]}{1.002 \left[\frac{\text{g}}{\text{m} \cdot \text{s}} \right] \cdot 0.66 \left[\text{m}^2 \right]} \right)^{1-0.22} \cdot \left(\frac{1.002 \left[\frac{\text{g}}{\text{m} \cdot \text{s}} \right]}{998200 \left[\frac{\text{g}}{\text{m}^3} \right] \cdot 6 \cdot 10^{-10} \left[\frac{\text{m}^2}{\text{s}} \right]} \right)^{0.5} \\ &= 0.016 \text{ s}^{-1} \end{aligned}$$

Now, we can calculate HTU

$$HTU = \frac{L_M}{M_w K_L a}$$

With $M_w = 55600 \text{ mol.m}^{-3}$, the molar density of water

So the height of one transfer unit is:

$$HTU = \frac{9.04 \cdot 10^2 \frac{\text{mol}}{\text{m}^2 \cdot \text{s}}}{55600 \frac{\text{mol}}{\text{m}^3} \cdot 0.016 \text{ s}^{-1}} = 1.02 \text{ m}$$

So, HTU= 1.02 m

Next NTU,

$$NTU = \left(\frac{R}{R-1} \right) \ln \left(\frac{\left(\frac{C_i}{C_0} \right) (R-1) + 1}{R} \right)$$

$$R = K_H \frac{Q_A}{Q_W} = 0.27 \cdot 100 = 27 [-]$$

$$C_i = 1 \frac{\text{g}}{\text{m}^3}$$

$$C_0 = 0.035 \frac{\text{g}}{\text{m}^3} \text{L}$$

$$NTU = \left(\frac{27}{26} \right) \cdot \ln \left(\frac{\left(\frac{1}{0.035} \right) \cdot (26) + 1}{27} \right) = 3.44$$

The number of transfer unit is: NTU=3.44

Finally, the height,

$$Z = NTU \cdot HTU = 1.02 \cdot 3.44 = 3.5 \text{ m}$$

The tower is 3.5 m tall

Problem 3:

Let's decide on the units we will use: m^3 , kg, m and min.

$$V_{TCA} = 10 \text{ m}^3$$

$$P_V = 0.13 \text{ atm}$$

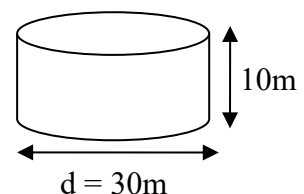
$$M_W = 133.4 \text{ g.mol}^{-1}$$

$$\rho_{TCA} = 1'325 \text{ kg.m}^{-3}$$

$$\rho_{wb} = 2'090 \text{ kg.m}^{-3}$$

$$\theta = 0.10 [-]$$

$$\varepsilon = 0.25$$



$$K'_H = 0.56$$

$$K_{OW} = 10^{-2.5}$$

$$T_{soil} = 20^\circ\text{C}$$

$$\rho_{air} = 1.28 \text{ kg} \cdot \text{m}^{-3}$$

$$K_D = 10^{-5} \frac{\text{m}^3}{\text{g}} * \frac{1000\text{g}}{1 \text{ kg}} = 10^{-2} \frac{\text{m}^3}{\text{kg}}$$

$$Q = 3 \frac{\text{m}^3}{\text{min}}$$

$$m_{TCA,tot} = \rho_{TCA} \cdot V_{TCA} = 1'325 \frac{\text{kg}}{\text{m}^3} \cdot 10\text{m}^3 = \underline{13'250 \text{ kg}}$$

Question: Time to remove 95% TCA with SVE.

The strategy is to first calculate the concentration of TCA in the gas phase and to determine its dependence on time. To do so, we need to calculate the volume of gas, the volume of water and the mass of dry soil in this system and the total volume of soil.

Calculate volume of soil contaminated

$$V_T = \pi r^2 H = \pi \cdot (15)^2 \cdot 8 = \underline{5'655\text{m}^3}$$

Bulk density of the soil ρ_b is linked to the wet bulk density by this relationship:

$$M_{soil,tot} = M_S + M_G + M_L$$

$$\rho_{wb} \cdot V_T = \rho_b V_T + \rho_{air} V_G + \rho_w V_L$$

$$= \rho_b V_T + \theta \rho_w V_T + (\varepsilon - \theta) \rho_{air} V_T$$

$$\left(\text{because } \theta = \frac{V_L}{V_T} \right) \quad \left(\text{because } \left(\frac{V_L + V_G}{V_T} - \frac{V_L}{V_T} \right) \rho_{air} \cdot V_T = \rho_{air} V_G \right)$$

$$\Rightarrow \rho_{wb} V_T = V_T (\rho_b + \theta \rho_w + (\varepsilon - \theta) \rho_{air})$$

$$\Rightarrow \rho_{wb} = \rho_b + \theta \rho_w + (\varepsilon - \theta) \rho_{air} \Rightarrow \rho_b = \rho_{wb} - \theta \rho_w - \rho_{air} (\varepsilon - \theta)$$

$$\rho_b = 2'090 \frac{\text{kg}}{\text{m}^3} - 0.10 \frac{\text{m}^3}{\text{m}^3} \cdot 1'000 \frac{\text{kg}}{\text{m}^3} - 1.28 \frac{\text{kg}}{\text{m}^3} * (0.15)$$

$$\underline{\rho_b = 1'989.8 \frac{\text{kg}}{\text{m}^3}}$$

$$V_L = \theta V_T = 0.1 * 5'655 \text{ m}^3 = 565.5 \text{ m}^3$$

$$V_G = (\varepsilon - \theta) V_T = 0.15 * 5'655 \text{ m}^3 = 848.25 \text{ m}^3$$

$$M_S = \rho_b V_T = 1'989.8 \frac{\text{kg}}{\text{m}^3} * 5'655 \text{ m}^3 = 11'252'319 \text{ kg}$$

Initial distribution of TCA

$$\begin{aligned}
m_{TCA,tot} &= m_{TCA,s} + m_{TCA,aq} + m_{TCA,g} \\
&= C_{TCA,s}M_S + C_{TCA,aq}V_L + C_{TCA,g}V_G \\
&= K_D M_S C_{TCA,aq} + C_{TCA,aq}V_L + K'_H C_{TCA,aq}V_G \\
\Rightarrow C_{TCA,aq} &= \frac{m_{TCA,tot}}{K_D M_S + V_L + K'_H V_G} \\
&= \frac{13'250 \text{ kg}}{10^{-2} \frac{\text{m}^3}{\text{kg}} \cdot 11'252'319 \text{ kg} + 565.5 \text{ m}^3 + 0.56 \cdot 848.25 \text{ m}^3} \\
C_{TCA,aq} &= 0.117 \frac{\text{kg TCA}}{\text{m}^3 \text{ water}}
\end{aligned}$$

$$C_{TCA,s} = K_D C_{TCA,aq} = 10^{-3} \frac{\text{m}^3}{\text{kg}} \cdot 0.117 \frac{\text{kg}}{\text{m}^3} = 1.17 \cdot 10^{-3} \frac{\text{kg}}{\text{kg}}$$

$$C_{TCA,g} = K'_H C_{TCA,aq} = 0.56 \cdot 0.117 \frac{\text{kg}}{\text{m}^3} = 0.070 \frac{\text{kg}}{\text{m}^3}$$

Calculate the amount of time the removal of 95% of TCA will require.

$$\frac{dm_{i,tot}}{dt} = -C_{i,g}(t) * Q_w = \frac{-K'_H * m_{i,tot}(t) * Q_w}{V_T (K_D \rho_b + \theta + K'_H(\varepsilon - \theta))}$$

$$\int_{t_0}^t \frac{dm_{i,tot}}{m_{i,tot}} = \int_{t_0}^t \frac{-K'_H * Q_w}{V_T (K_D \rho_b + \theta + K'_H(\varepsilon - \theta))} dt$$

$$\ln\left(\frac{m_{i,tot}(t)}{m_{i,tot}(t_0)}\right) = \frac{-K'_H * Q_w}{V_T (K_D \rho_b + \theta + K'_H(\varepsilon - \theta))} dt$$

$$t = -\frac{\ln\left(\frac{m_{i,tot}(t)}{m_{i,tot}(t_0)}\right)}{K'_H * Q_w} * V_T (K_D \rho_b + \theta + K'_H(\varepsilon - \theta))$$

$$\text{for 95\% removal, } \frac{m_{TCA,tot}(t)}{m_{TCA,tot}(t_0)} = 0.05$$

$$t = -\frac{\ln(0.05)}{0.56 * 3 \frac{\text{m}^3}{\text{min}}} * 5655 \text{ m}^3 * (10^{-2} \frac{\text{m}^3}{\text{kg}} * 1'989.8 \frac{\text{kg}}{\text{m}^3} + 0.1 + 0.56 * (0.15))$$

$$t = 2.03 * 10^5 \text{ min} = 140 \text{ days}$$

Additional comment:

Saturation concentration of TCA in the gas phase is given by the ideal gas law $PV=nRT$, rearranged: $PV=nRT \Rightarrow n/V= P/RT$ and to get the concentration in units of mass per volume, we multiply by the molecular weight of TCA:

So we have: $C_{\text{sat, TCA}}= M_W P/RT$

$$C_{\text{sat,TCA}} = \frac{M_W \cdot P_V}{RT} = \frac{133 \frac{\text{g}}{\text{mol}} \cdot 0.13 \text{ atm}}{0.08205 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \cdot 293 \text{ K}}$$

$$C_{\text{sat,TCA}} = 0.73 \frac{\text{kg}}{\text{m}^3}$$

The mass transfer rate is fast since there is a substantial gradient: the difference between the air saturation of TCA and the actual concentration is large.

Problem 4:

Select units for this problem: kg for soil, g for TPH, m³ for volume and day for time

Site characteristics:

Surface area of contamination $S=20 \text{ m}^2$

Height of contamination $h=6 \text{ m}$

Total volume of soil contaminated $V_T=S*h= 120 \text{ m}^3$

$\rho_b=1400 \text{ kg/m}^3$

Porosity $\varepsilon=0.3 [-]$

Soil moisture content $\theta=0.05 [-]$

Flow rate of air injected $Q = \frac{3.5 \text{ m}^3}{\text{min}} * \frac{60 \text{ min}}{\text{h}} * \frac{24 \text{ h}}{\text{d}} = 5040 \frac{\text{m}^3}{\text{d}}$

Contaminant characteristics:

Initial: $C_{TPH, total} = 500 \frac{\text{mg TPH}}{\text{kg wet soil}} = 0.5 \frac{\text{g TPH}}{\text{kg wet soil}}$

Target: $C_{TPH, total} = 50 \text{ mg} \frac{\text{TPH}}{\text{kg wet soil}} = 0.05 \frac{\text{g TPH}}{\text{kg wet soil}}$

$K_H'=2.08 [-]$

$K_D = \frac{0.03 \text{ m}^3 \text{ water}}{\text{kg soil}}$

O₂ needed per g of TPH = 3.33 g O₂/g TPH

Molar volume of gas = 0.0224 m³/mol

$C_{O_2} = 0.21 \frac{\text{m}^3 O_2}{\text{m}^3 \text{ air}}$

$D_{O_2} = 1,330 \frac{\text{mg } O_2}{\text{L } O_2} * \frac{1000 \text{ L } O_2}{1 \text{ m}^3 O_2} * \frac{1 \text{ g } O_2}{1000 \text{ mg } O_2} = 1330 \frac{\text{g } O_2}{\text{m}^3 O_2}$

Part 1: Bioventing

1. Oxygen utilization rate

$$\begin{aligned} Q &= \frac{k_{O_2} * V_T}{C_{O_2}} & \rightarrow & k_{O_2} = \frac{Q C_{O_2}}{V_T} \\ & & \rightarrow & k_{O_2} = \frac{5040 \frac{\text{m}^3 \text{ air}}{\text{d}} * 0.21 \frac{\text{m}^3 O_2}{\text{m}^3 \text{ air}}}{120 \text{ m}^3 \text{ wet soil}} \\ & & \rightarrow & k_{O_2} = 8.8 \frac{\text{m}^3 O_2}{\text{m}^3 \text{ wet soil} * \text{day}} \end{aligned}$$

2. Biodegradation rate

$$k_B = \frac{k_{O_2} * D_{O_2} * R_{C/O}}{\rho_{wb}}$$

We need to calculate the wet bulk density ρ_{wb}

$$\rho_{wb} = \frac{M_s + M_L}{V_T} = \rho_b + \rho_L \theta = 1,400 \frac{kg}{m^3} + 997 \frac{kg}{m^3} * 0.05[-] = 1,450 \frac{kg}{m^3}$$

$$C = \text{ratio of Carbon to } O_2 = 0.3 \frac{g \text{ of Carbon}}{g \text{ of } O_2}$$

$$k_B = \frac{k_{O_2} * D_{O_2} * R_{C/O}}{\rho_b + \theta \rho_w + (\epsilon - \theta) \rho_{air}}$$

$$\rightarrow k_B = \frac{8.8 \frac{m^3 O_2}{m^3 \text{ wet soil} * \text{day}} * 0.24 \frac{g \text{ of C}}{g \text{ of } O_2} * 1,330 \frac{g O_2}{m^3 O_2}}{1,400 \frac{kg \text{ wet soil}}{m^3 \text{ wet soil}} + 0.05 * 1000 \frac{kg}{m^3} + (0.3 - 0.05) * 1.225 \frac{kg}{m^3}} = 1.92 \frac{g \text{ of TPH C}}{kg \text{ wet soil} * \text{day}}$$

$$k_B = 1.92 \frac{g \text{ of TPH C}}{kg \text{ wet soil} * \text{day}} * \frac{1 \text{ kg}}{1000 \text{ g}} = 1.92 * 10^{-3} \frac{kg \text{ of TPH C}}{kg \text{ wet soil} * \text{day}}$$

3. First-order kinetics

$$C_t = C_0 e^{-k_B t}$$

$$C_t = C_0 * e^{-1.92 * 10^{-3} \frac{kg \text{ TPH}}{kg \text{ soil} * \text{day}} * t}$$

$$t = \frac{\ln\left(\frac{C_{final}}{C_{initial}}\right)}{-k_B}$$

$$t = \frac{\ln\left(\frac{0.05}{0.5}\right)}{-1.92 * 10^{-3}} = 1199.3 \text{ days} = 3.4 \text{ years}$$

Part 2: Soil Vapor Extraction

4. $C_{TPH,g} = ?$

$$Q_w = 5 \frac{m^3}{\text{day}}$$

$$V_T = 6 * 20 \text{ m}^2 = 120 \text{ m}^3$$

$$V_G = (\epsilon - \theta) V_T = 0.25 * 120 \text{ m}^3 = 30 \text{ m}^3$$

$$V_L = V_T \epsilon - V_G = 120 \text{ m}^3 * 0.3 - 30 \text{ m}^3 = 6 \text{ m}^3$$

$$M_L = 6 \text{ m}^3 * 997 \frac{kg}{m^3} = 5,982 \text{ kg}$$

$$M_s = \rho_b V_T = 168,000 \text{ kg dry soil}$$

$$m_{TPH,total} = m_{TPH,s} + m_{TPH,aq} + m_{TPH,g}$$

$$C_{TPH,total} * (M_s + M_L) = C_{TPH,s} * M_s + C_{TPH,aq} * V_L + C_{TPH,g} * V_G$$

$$C_{TPH,total} * (M_s + M_L) = C_{TPH,aq} * K_D * M_s + C_{TPH,aq} * V_L + C_{TPH,aq} * K'_H * V_G$$

$$C_{TPH,total} * (M_s + M_L) = C_{TPH,aq} * (K_D * M_s + V_L + K'_H * V_G)$$

$$C_{TPH,aq} = \frac{C_{TPH,total} * (M_s + M_L)}{(K_D * M_s + V_L + K'_H * V_G)}$$

$$C_{TPH,aq} = \frac{\frac{0.5 \text{ g TPH}}{\text{kg wet soil}} \cdot (168'000 \text{ kg dry soil} + 5'982 \text{ kg water})}{\frac{0.03 \text{ m}^3 \text{ water}}{\text{kg dry soil}} \cdot 168'000 \text{ kg dry soil} + 6 \text{ m}^3 \text{ water} + 2.08 \cdot 30 \text{ m}^3 \text{ air}}$$

$$C_{TPH,aq} = 17.0 \frac{\text{g}}{\text{m}^3}$$

$$C_{TPH,g} = K'_H * C_{TPH,aq} = 2.08 * 17.0 \frac{\text{g}}{\text{m}^3} = 35.4 \frac{\text{g}}{\text{m}^3}$$

5. How long to reach the regulatory goal?

$$\begin{aligned} \frac{dm_{TPH,tot}(t)}{dt} &= -C_{TPH,g}(t) * Q_w \\ \rightarrow \int \frac{dm_{TPH,tot}}{dt}(t) * dt &= - \int \frac{K'_H m_{TPH,tot}(t)}{M_s K_D + K'_H V_G + V_L} Q_w * dt \\ \rightarrow \int \frac{dm_{TPH,tot}}{m_{TPH,tot}} &= - \int \frac{K'_H Q_w}{M_s K_D + K'_H V_G + V_L} * dt \\ \rightarrow \ln \left(\frac{m_{TPH,tot}(t)}{m_{TPH,tot}(t_0)} \right) &= - \frac{K'_H Q_w}{M_s K_D + K'_H V_G + V_L} (t - t_0) \end{aligned}$$

$$t = - \frac{\ln \left(\frac{m_{TPH,tot}(t)}{m_{TPH,tot}(t_0)} \right)}{K'_H * Q_w} * (M_s K_D + K'_H V_G + V_L)$$

$$m_{TPH,total,final} = C_{TPH,total,final} * (M_s + M_L)$$

$$m_{TPH,total,final} = \frac{0.05 \text{ g TPH}}{\text{kg wet soil}} * (168,000 \text{ kg dry soil} + 5,982 \text{ kg water}) = 8699 \text{ g TPH}$$

$$m_{TPH,total,initial} = \frac{0.5 \text{ g TPH}}{\text{kg wet soil}} * (168,000 \text{ kg dry soil} + 5,982 \text{ kg water}) = 86991 \text{ g TPH}$$

$$t = - \frac{\ln \left(\frac{8699}{86991} \right)}{2.08 * 5 \frac{\text{m}^3}{\text{day}}} * \left(168000 \text{ kg} * \frac{0.03 \text{ m}^3}{\text{kg}} + 2.08 * 30 \text{ m}^3 + 6 \text{ m}^3 \right) = 1131 \text{ days}$$

$$t = 3.1 \text{ years}$$

What is the best solution?

SVE takes about the same time in this case, but it requires a much lower flow rate. Which means a lower energy consumption and consequently cheaper. It is the preferable option.